The challenges of building inner sea offshore wind farms - the cases of Lillgrund and Anholt

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Abstract

Offshore wind power installation is a growing business within the construction sectorasoffshore wind represents large available renewable energy resources and availability of space. Offshore wind energy is however expensive due to the large capital expenses. The construction of an offshore wind farm encounters many challenges throughout its construction processes. Therefore“inner sea” offshore wind farms receive increasing interest, due to their assumed attractive features of reduced costs of erection and operation. The aim of this paper is to identify the challenges encountered during the installation phase of offshore wind turbines at “inner sea” conditions, understood as the Baltic Sea region and neighbouring areas. Offshore wind farm installation is conceptualised as a building operation. Consequently, theories on construction management, operations management and strategy, supply chain, building logistics and concepts on offshore wind farm development were used. A qualitative approach using interviews and literature. Out of seven farms in operation in the southern Baltic, Øresund and Kattegat, two were selected. Interviews were conducted with professionals that were involved in installation of Anholt and Lillgrund. The analysis showed that installation challenges can either be due to local natural conditions or technical issues related to equipment, planning, technology and work practices. At Lillgrund challenges were bad weather conditions and breakdown of a vessel, causing a delay of export cable installation and the tight tolerances for the bolts at the tower-foundation interface. At Anholt, a soft seabed necessitated the abandonment of some turbine positions. Irregular supply by the turbine supplier forced the vessel operator to change planning, andit was needed to handle gas leaks from the sea bed.Installation challenges grows as wind turbines are becoming bigger and heavier and locations go further from shore. Developers and contractors must continuously innovate processes and equipment to overcome these challenges.

Keywords: Offshore construction, offshore wind farms, inner sea, Baltic Sea,

1. Introduction

The global energy consumption is projected to grow by 56 % between 2010 and 2040 (U.S. Energy Information Administration, 2016). A larger percentage of the global energy used is mainly from non-renewable sources such as fossil fuel. Non-renewable energy is associated with different negative environmental impacts such as greenhouse gas emission (Rodrigues et al., 2015). As countries in the European Union therefore seek to meet this challenge through renewable energy use, wind energy is increasingly being adopted for electricity generation. The interest for offshore wind is also increasing and is the focus here.However, offshore wind farm development is still constrained by large capital investments resulting from among others costly marine foundations, expensive installation procedures and limited access for operation and maintenance (Bilgili et al., 2011). The development process is further complicated by the involvement of different stakeholders, a complex set of contracts (Koch 2014) as well as increasing interest in locating larger offshore wind farms farther offshore and in deeper water (EWEA, 2011). As result, offshore wind energy remains more expensive and less competitive than other energy sources.Against the background of increasing interest in offshore wind farm development coupled with complexities in the offshore development processes, there is need to continuously reduce the costs and constraints by improving the operating methodology involved in offshore wind farm planning, design and installation processes. This can be achieved by among others learning from challenges encountered and processes employed on completed projects.One particular strategy is to place offshore wind turbine parks under less harsh conditions than known from the North Sea and attempt to exploit “inner sea” conditions of more shallow waters, closeness to land and an environment with lower salinity (Swedish Energy Agency, SEA, 2015).

The aim of the research was to identify the challenges faced in the installation of offshore wind farms (i.e., from installation of foundations to commissioning) with specific focus on offshore activities within the Baltic Sea region and neighbouring waters such as the Gulf of Bothnia, Øresund and Kattegat.To achieve the aim, the objective was to find answers to the following questions:What are the major decisions to be considered for an installation of offshore wind farm?What are the challenges faced in the installation of the different components of wind turbines and how do the identified challenges arise?What are the persisting challenges? Why and how can they be mitigated?Two cases of “inner sea” wind farms are studied; Anholt and Lillgrund. Anholt is situated in Kattegat, has a capacity of 400 MW, was inaugurated in 2013 and is operated by DONG. Lillgrund is situated in Øresund close to Malmö, has a capacity of 110 MW, was inaugurated in 2008 and is operated byVattenfallVindkraft. The paper is structured in the usual way, commencing with theory for answering our research question, method, then the two cases, an analytical discussion and finally a conclusion.

2. Theoretical framework

The framework is developed through combining concepts of operations management and-strategy, supply network strategy and more experience based on general concepts of offshore wind farm construction.

2.1 Operations management and strategy

Operations management is the activity of managing the resources that create and deliver services and products (Slack et al., 2013). The principal process is transforming inputs into outputs. Be it services or products. In construction projects, construction sites are the points where the final products of the construction industry are produced, by transforming material resources using the human workforce, equipment and technologies. Managing a construction project needs to be done by considering various aspects involved in the construction industry such as human interaction, transformation of matter, institutions, lean and performance. The aspects of the construction processes have both tangible and intangible effects and also impact the economic efficiency and productivity.Slack and Lewis (2011) define operation strategy as; ‘‘The total pattern of decisions which shape the long term capabilities of any type of operation and their contribution to overall strategy through the reconciliation of market requirements and operations resources.’’ In the management of operations resources, strategic decision have to be made in four areas which include; capacity strategy, process technology, product development and organisation development,supply networks, procurement and logistics(Slack and Lewis 2011). These areas are described in the following starting with strategy of capacity. Capacity refers to the resources available to perform required activities within a given period of time. Capacity strategy is concerned with how capacity and facilities are configured and calculating required capacity level, when changes in capacity should be made (Slack and Lewis, 2011). Capacity levels influence an organisation’s ability to meet and respond to customer demands and also affect the product lead time, ability to compete and operation costs. Low capacity limits growth whereas high capacity levels lead to underutilisation of labour, machinery with consequent high costs and low profitability (Slack and Lewis, 2011, Aswathappa, 2010). An appropriate level of capacity has to be maintained during operation. Capacity planning activities involve; forecasting capacity needs for products, identifying sources of capacity to meet needs and developing capacity alternatives (Aswathappa, 2010). Operations management is also concerned with the coordination of manufacturing activities in its broad sense. This is done through production planning and control, as well as supply chain management. Scheduling is one of the functions performed under production planning and control. It is concerned with setting the production time as well asstart and finish for activities. In offshore wind farm operations, the scheduling is performed based on available labour and equipment. The schedule is developed based on the estimated time taken to install parts and the processes involved in installation operation from pre-assembly to installation onsite (Thomsen, 2014).Scheduling of offshore installation activities is highly dependent on weather conditions, requiring schedulers to make optimal schedules based on the installation scenario selected (Scholz-Reiter et al., 2010).Process technology involves the choice and development of systems, machines and processes that transform resources into finished products and services. Thomsen (2014) highlights the installation vessels as being important items that are necessary for timely installation of offshore wind farm components. The schedule of the installation process is heavily reliant on the capacity and operation of the installation vessels, meaning that a failure to timely contract with vessel suppliers would most likely jeopardise the project schedule. A variety of vessels are available for use in the different phases of the installation process. A trade-off however has to be made between the costs and risks imposed by the different combinations of vessel fleets (Kaiser and Snyder, 2010). Finally, but in a sense first in the operation processes,a strategy for product development should be developed and deployed.The product development is significantly affected by speed, scale of market and technological changes, which impact on the appropriate process to be used (Slack and Lewis, 2011). This also includes offshore wind power. As the number of competitors increases, the customers become more demanding in terms of products and services. A good planning technique in terms of time and resources, management skills and tools combined with a proper organisation enable the achievement of the resulting performance objectives (Koch 2014).

2.2. Supply network strategy including procurement and logistics

Lambert (2004) defined supply chain management as ‘‘the integration of business processes from end user through original suppliers that provides products, services, and information that add value for customers”. And logistics management is the part of supply chain management that plans, implements and controls the efficient, effective flow and storage of goods, services, and related information between the point of origin to the customers (Slack and Lewis, 2011). Logistics management deals with supply and demand planning, order processing, materials handling, storage andinventory management. The installation of offshore wind turbines has to take into account the different lead times, sizes of the different wind farm components as well as weather dependency of offshore operations.For storing of material and resources in order to exploit good weather periods for intensive installation work, minimise delays in transport, handling and installation of offshore wind farms it is suggested to have logistical planning and renting an appropriate staging area in a port that is favourably close to the offshore site (Thomsen, 2014). The offshore supply chain must be flexible organised so that the installation is not delayed by material shortages. A continuous supply must be guaranteed for the whole process. Gerdes (2010) suggests and line production outline of the installation procedure and supply chain out.

2.3. Wind Turbine transportation and installation process

The components of wind turbine; foundations, tower, nacelle and blades are to be fixed together to complete the installation. As part of the installation process, the components need to be transported from either the point of manufacture or a port to the installation site. The installation of foundations and turbines of offshore wind farms requires the use of a variety of marine vessels dependent on system generation capacity, water depth, soil conditions at site, costs and risk exposure (Kaiser and Snyder, 2012).The installation vessels are used for transfer of support structures and turbines to offshore sites, provision of stable platforms for lifting and installation operations and accommodation for ship crew and personnel (Leanwind 2014). Critical characteristics are maximum lift height and weight, speed and number of turbines carried (Kaiser and Snyder 2012).Installation encompasses four elements; foundations, turbines, cables and substations. There are four basic types of foundations that can be used in offshore wind farms namely; monopile, gravity, tripod and jacket foundations (Kaiser and Snyder 2012). The choice of foundation used is dependent on specific conditions on site such as water depth and sea environment, maximum wind speed, soil type, and distance from port (Leanwind2014). Installation of turbines, which follows the foundations and turbine installation, is highly sensitive to weather conditions and requires lifting of heavy components up to the height of the hub. Vessel requirements for turbine installation are dependent on; turbine weight, hub height, and installation and transportation (degree of pre-assembly) strategy adopted (Leanwind 2014). Depending on the degree of pre-assembly onshore, 6 common installation strategies are available (Leanwind, 2014), ranging from one involving low degree of onshore pre-assembly and a large number ofoffshorelifts, to that involving pre-assembly of the entire turbine onshore and one offshore lift (Kaiser and Snyder 2010). The former strategy is often suitable for sites located far from shore to maximise use of space on the transportation vessels. The latter strategy involves transporting the assembled turbine and can be challenging and requires employing heavy lift vessels with large capacity cranes. A number of methods are available for the installation of cables, such as remote operated vehicles, under water ploughs or through excavation. An offshore substationconverts generated electricity for transmission to the onshore grid (Barlow et al., 2015). The installation sequence for offshore substations is similar to the turbines. Summarizing operations management and strategy to producewind farms, involves strategic decisions in sevenmain areas; capacity strategy, process technology, product development and organisation development, supply networks, procurement, installation and logistics. Importantly this type of operations involves a strong dependency of the final location of the product and its features, i.e distance for shore, water depth etc. A feature that distinguish it fromoperations management in manufacturing and is similar to those of more complex engineering construction products such as civil engineering and process plants.

3. Method

The research was conducted to identify the challenges in the installation phase of offshore wind turbines and focused on learning from completed projects at ”inner sea” conditions. A qualitative study design, using personal interviews with offshore wind power professionals, was employed,to map the encountered challenges in practice. Offshore installation as understood as an operation, and theory about operations management, operations strategy, supply chain as well as concepts on offshore wind farm development were adopted and used for sensitizing the data collection and analysing and discussing the collected data. A literature search was conducted using Chalmers library search engine “Summons” and Google Scholar. “Summons” is an aggregated search engine combining a number of sources including Science Direct, Proquest, and Scopus. Specific keywords such as wind turbine, offshore wind power, offshore oil and gas industry and challenges in offshore projects were used to gather relevant academic articles. A total of 52 academic journal articles, books and reports were screened out of which 39 were considered and read.The obtained literature and other information concerning previous experiences from offshore wind farms were studied to compile the theory and develop an insight of challenges faced in installation of offshore wind power projects. Supplementary information was obtained through conducting interviews and email correspondence with professionals in the industry, and from websites dedicated to offshore wind, such as 4Coffshore.Case studies were selected from wind farms constructed within the Baltic Sea, the Gulf of Bothnia and inner Danish-Swedish waters such as Kattegat, Øresund, Storebæltover the past 10 years (2005 – 2015). The considered farms are shown in Table 1. With the exception of EnBW Baltic 2, the rest of the wind farms could be categorised within the 20-20 segment (i.e. constructed less than 20 km from shore and in water depth of less than 20 m) with the four gravity based foundation structures and three monopile. Also some older farms such as Middelgrunden (2001) and Sprogø (2003) was deselected to assure contemporary operations management methods.

Table 4: Existing ”inner sea” offshore wind turbine parks

EXISTING

Wind farm	Capacity (MW)	Turbine capacity (MW)	Construction year	Depth Range (m)	Km to shore	Foundation	Developer	Owner	Country
Anholt	400	3,6	2013	15	20	Monopile	DONG Energy	DONG Energy	Denmark
EnBW Baltic 2	288	3,6	2015	23-44	35.4	Monopile & Jacket	EnBW Baltic 2	EnBW Energie	Germany
EnBW Baltic 1	48,3	2,3	2011	16-19	16	Monopile	EnBW Baltic 1	EnBW Energie	Germany
Rødsand II	207	2,3	2010	6-12	9	Gravity	E.ON	E.ON	Denmark
Lillgrund	110	2,3	2008	4-13	9	Gravity	Vattenfall	Vattenfall	Sweden
Karehamn	48	3	2013	6-20	7	Gravity	E.ON	E.ON	Sweden
Sprogø	21	3	2009	6-16	10	Gravity	Sund&Baelt	Sund&Baelt	Denmark

A mapping of the planned ”inner sea” projects was also carried out, to evaluate the potential for learnings from existing ”inner sea” parks. This mapping showed that the national areas of Denmark, Germany, Poland and Sweden together have some 6300 MW planned “inner sea” offshore parks in the greater Baltic Sea area.Semi structured interviews were conducted with selected professionals; most of them being project managers, from companies involved in offshore wind farm development activities, but also service providers and other experienced professionals. The interviewees were involved in installation of Anholt or Lillgrund wind parks working for developers, contractors or service providers. Most of the interviewees were suggested by their respective companies. A total of six interviews was done related to offshore wind farms particularly in North and Baltic Sea. An interview guide was developed based on the research objectives, questions and hypotheses derived from theory. Obtained results on challenges encountered in wind farm installation were gathered and discussed. The differences and similarities were highlighted and the most often occurring challenges were identified together with their effects and current status. Depending on the status (mitigated/unmitigated) of the identified challenges, suggestions were made on what considerations can be made by developers and contractors to minimise their occurrence.

4. Case: Lillgrund

Lillgrund wind power plant is located in the Öresund area 7 km off the southern coast of Sweden in a water depth ranging from 4 to 12 m. The wind farm has a capacity of 110 MW generated from 48 Siemens 2.3 MW Mk II turbines. The shallow water and proximity to the coast were advantageous. They enabled easy access during construction and maintenance, use of a short export cable and control of the foundation cost. The wind farm was constructed 2006-07 with support from the SEA. The project was executed under two major contracts; one for foundations and seabed preparation (Pihl-Hochtief joint venture) and the other for wind turbines and electrical system (Siemens wind power). Lillgrund is founded on gravity based concrete foundations, with a hollow structure, which are filled with ballast once placed on site. The farm also has an offshore substation(Flodérus, 2008). Due to the varying water levels on site, five different heights of foundations were produced ranging from 10-14 m and a base width of 19 m. The foundations were prefabricated directly on rented transportation barges in Poland in the harbour of Swinoujscie (Jeppsson et al., 2008). Foundation production works were carried out simultaneously with dredging works on site. The dredging worksinvolved cutting the seabed to required profiles .Divers were employed to check that the dredging works were properly done before the foundations could be placed. The foundations were towed to site on barges and placed on the seabed by means of a crane barge supplied by Eide contracting AS. The foundations were protected from scouring due to ocean currents by placing a layer of rock fill (Jeppsson et al., 2008). Each turbine consists of a 73 m high cylindrical tower weighing 134 tonnes, an 82 tonnes nacelle and 60 tonnes rotor. The turbine nacelles, blades and tower were transported by road from the Siemens’ factory in Brande, West Jutland in Denmark to the installation port at Nyborg. Some degree of onshore pre-assembly was performed specifically the attachment of the three blades to the hub at the installation port. The preassembled blades, the tower pieces and the nacelle were transported to the installation point on a jack up vessel called Sea power (A2SEA). The vessel has the capacity and sufficient area to install three wind turbines from one trip (Jeppsson et al., 2008, Flodérus, 2008). A total of four lifting operations were employed during the installation. The installation time including the transit time to the installation site by the installation vessel for the three turbines that the sea power would carry was five days. The actual installation time for three turbines on site was however two days (Flodérus, 2008). The installation sequence described above has since become out fashioneddue to the fact that it requires a large space on the installation vessels to transport a fully assembled rotor Larsen (interview, 2016-03-10). At the time of constructing Lillgrund, it was problematic to lift a single blade when operating offshore since it was highly weather sensitive. However, according to an interviewee from A2SEA, the method adopted for installation is sometimes dictated by the turbine manufacturers. In early days, it was not possible to turn the rotor shaft while the turbine was not balanced by 3 blades, but it has since become possible to install single bladeswith the introduction of the blade gripperJohannsen (interview, 2016-05-03). This ensures optimum use of space on the installation vessel and minimises the number of trips between the wind farm and the installation harbour. Lillgrund cabling consists of a 130 kV electrical system whereof 7 km isan export cable at sea and 2 km cable is on land, connected to E.ON'sonshore station (Jeppsson et al., 2008). Siemens subcontracted the cable supply and installation work package to ABB which used four subcontractors, responsible for export cable installation, diving, transport and inter-array cable installation (Unosson, 2009). Two vessels were used for laying the export cable and inter array cables respectively in 1 m deep trenches. A Remotely Operated Vehicle (ROV) and divers were employed to ensure that the cables were properly laid in the excavated trenches (Unosson, 2009).The offshore substation was built by Bladt industries andSiemens was subcontractors on the electrical part of the substation.

5. Case: Anholt

Anholt wind farm is located between Djursland and the island of Anholt located in Kattegat Sea in Denmark and operated by DONG. The wind farm consists of 111 3,6 MW wind turbines. The total farm capacity is 400 MW. It is located at a sea depth of 15-19 m. A transition piece connects the tower and a monopile foundation of a diameter of 5 m driven into the seabed. The port of Grenaa at a distance 20 km away, was used during both installation works and is used for maintenance. The project also includes a substation and submarine electricity cable connected to Grenaa. The major soil types encountered during geotechnical study were gravel, sand, clay and in some areas small organic content - which fit with steel monopile foundation. The construction works took place 2012-13. The offshore substation, the power export cable to shore, and the connection to the main power grid on land is provided by the state. Main suppliers to DONG energy were Siemens Wind Power A/S for wind turbines, Siemens A/S for offshore substation electrical equipment, MT Højgaard for civil engineering, AH Industries for wind mill towers and nacelles and Nexans Deutschland GmbH for array cables. About 23 other sub-contractors participated (Pau, 2015). They include Ballast Nedam Equipment services for the foundation installation vessel, A2SEA for wind turbine installation vessels, Visser& Smit Marine, infield cables and HvideSandesSkibsbyggeri for two service vessels. GEO Engineering Consultant was hired to carry out geotechnical and geophysical investigations and Ramboll made environmental,maritime studies and design of offshore substation and foundation. About one hundred vessels were involved in the construction and a total of 3,000 employees 1,000 fulltime (Pau, 2015). During the installation period the wind turbine components were stored at Grenaa port and transported to site by a barge and a vessel. Foundations consisting of a 37-54 m round steel pile with a diameter of approximately 5 m. The 111 monopiles foundations were installed by MT Højgaard A/S using Ballast Nedam heavy lift vessel-Svanen, and the transition pieces by the heavy-lift vessel Jumbo Javelin rented from A2SEA Company. The steel monopiles were manufactured by Bladt Industries. To install the monopile, the first step was to install plugs and rigging at harbour then launch the plugged monopile to the water using sheerlegs. The plugged monopile was able to float on water surface and towed to site for installation by a vessel. It took about 7-8 hours to drive the monopile into the seabed. A transition piece was then installed by using a vessel, capable of carrying 9 pieces on each load. On site the 170 tons' transition pieces were lifted and grouted on top of the monopiles. The turbines were supplied and installed with nacelle and three blades. To erect wind turbines, a crane mounted on the jack-up vessels was used to lift the wind turbine components into place in six lifting operations. The lifting operation consisted of 2 pieces of tower, 1 nacelle, 3 blades and no pre-assembly was done onshore. The jack-up barges or installation vessels, "stand" on the seabed and create a stable platform. Four different turbine installation vessels from A2SEA were deployed at the same time during the installation, carried out in the following processes: The vessel loaded components for one or two turbines at the port and transported them to the site. At the site the vessel jack-up and start installation of one turbine starting from lower part of the tower, upper part, nacelle and three blades. Once a turbine is completed the vessel goes down to the floating level, starts sailing to the next turbine location, and jack-up again to installation of the second turbine. When finished, the vessel sails from the site back to port for new loading (Thomsen, 2014). Energinet.dk was responsible for establishing an offshore substation and power export cable to shore.The whole structure,a concrete gravity base of 4,000 tons together with steel jacket structure of 800 tons was floated and towed to the Anholt site from Copenhagen. A 160 km buried submarine array cable, connects the 111 turbines to the offshore substation. From the substation, the 25 km long submarine export cable, buried in 1 m into the seabed, transmits the power to Grenaa (Pau, 2015).

6. Discussion

From the two case descriptions three main challenges at Lillgrundand Anholt are discussed. At Lillgrund, firstly the export cable installation was delayed two monthsbecause of bad weather conditions at sea and the breakdown of the thrusters/propellers of the vessel Nautilus Maxi. It was needed to re-open the trenches which had consequently been refilled with mud during the period of inactivity. Second the tight tolerances of the bolts for the tower-foundation interface proved problematic. Third unevenness in the concrete foundations rendered some bolts too short. Therefore, cutting of the concrete had to be done to achieve the required bolt height. These challenges relate a lot to the dependency of location and confirm its crucial role in this type of operations management. But it also relates to process technology and product features.At Anholt the three main challenges were, first the soft seabed in the north part of the park identified by the geotechnical survey. The use of vessels with jack-up function, necessitated the abandonment of some turbine positions, causing the change of the final park layout in a non-optimal manner. Second irregular supply by the turbine supplier, forced the vessel operator to change planning accordingly. Third World war II subsea mines delayed geophysical surveys of the seabed. Lastly special attention was also needed to handle gas leaks from the sea bed.These challenges relate for a large part to the particular location, but also to the manufacturing of the windturbines. Some similar challenges also occurred in the two cases. As the turbines become larger, they also require massive foundations. This leads to challenges of lifting heavy and big size components. The heavy weights render the currently available vessels insufficient for lifting. Additionally, logistical challenges arise since the components can no longer be transported by road. The challenges found in the two cases can thus be categorised as both site specific and crosscutting. Some of the general challenges arise from nature like weather conditions and difficulties in fully predicting ground conditions whereas other technical challenges such as heavy weight components originated from the production of larger turbines. The site specific challenges such as irregular supply and inability to produce in accordance with the required standards are attributable to a limited number of suppliers. The managers involved in the installation phase of Lillgrund and Anholt considered preparation and planning as vital elements(Gerdes 2010 and Thomsen 2014). The planning involved making decisions on the type of vessels for the installation, the interpretation of both weather forecasts and geotechnical investigations, the form of contract, procuring contractors and selecting appropriate installation harbours. The planning activity was also guided by among others knowledge and the experiences gained from previous operations. In order to minimise ambiguities the planners attempted to use methods that have been proved previously for instance the method for selection of wind turbines and installation process used at Lillgrund. Since the installation of wind turbine involved various contractors and service providers, both developers and contractors agreed to work in close cooperation. Such kind of cooperation was highly needed from design phase to facilitate the early identification and mitigation of problems that could arise in the later phases of the project. For instance to avoid lifting challenges that might occur, the designers would need to be aware of the availability of appropriate lifting vessels on the market. Both Lillgrund and Anholt had an installation period that was, according to interviewees, short and with a strict time frame therefore they were forced to use any available weather window for installation activities. Slack and Lewis (2011) suggest that in the management of operations resources, decisions have to be made in four areas capacity, process technology, supply networks and organisation development. All interviewees agreed that the choice of right installation vessels with the right capacity was the first step during a planning of a wind farm installation. For example to avoid the heavy lifting challenges that could occur, at Anholt, the contractor chose to tow the foundation to site instead of loading them on vessels because it was not quite easy to lift the 460 ton monopile whereas at Lillgrund, the gravity foundation were directly manufactured and transported to site on the barges.Due to favourable sea conditions, it was possible to use one type of vessel for the installation. The contractor chose the same equipment that had been used in harsher conditions at Horns Rev 1 in the North Sea. Contrary to Lillgrund, vessel selection and planning at Anholt was highly demanding. It was necessary for the contractor to find a unique and flexible solution. One of the fascinating solutions was using a flexible fleet where the contractor planned and achieved turbine installation using four different installation vessels. Adopting this flexible fleet of vessels shielded the customer fromadditional costs of vessel capacity.The interviewees confirmed Slack and Lewis (2011) and Kaiser and Snyder (2010)'s point about flexibility in operation resources in that they had a variety of vessels available. Literature reviewed pointed out the shortage of purpose built vessels. However, from the interviews conducted, the interviewees asserted that there was sufficient capacity of vessels. Notwithstanding this assertion, the vessels were also in demand from other sectors such as telecommunication and oil and gas sectors. Consequently, there was uncertainty on the availability of vessels due to variability in demands from the different sectors. There was also concern over low installation speed due to the use of non-purpose built vessels, which not always are fully appropriated to the tasks. As far as logistics is concerned the interviewees strongly emphasised that the installation harbour was problematic, which is in line with Thomsen (2014). The absence of sufficient purpose built harbours for offshore operation hindered the installation process since priority was given to commercial vessels over offshore vessels. A purpose built harbour further away from site is thus preferable than a non-dedicated harbour located close to site. In the Baltic Sea region and its neighbouring waters, attempts have been made to resolve the harbour problem by building purpose built harbours such as Nyborg and Grenaa. The question that remains is whether they will remain suitable for handling heavy turbine components for future developments as well as to accommodate large size vessels. As the construction of offshore wind farm requires onshore space for pre assembly, loading, unloading and lifting activities of heavy and larger components for a long period it is challenging to find appropriate spatial facilities that can be occupied for a period up to three years. According to some of the interviewees, it is expensive to build purpose built harbours for every wind farm activity. It is not economically feasible to construct a harbour for each wind farm; a more appropriate solution would be to develop a number of strategically located harbours that can be used as need arises. With regards to product development, most interviewees recognised the need for strategic development and organisation in their respective companies in order to compete with future challenges that may arise. The interviewees posited that future offshore installations would be in more challenging conditions than previously, the reason for continuous development of processes and equipment to overcome the expected challenges. The weather dependency was highlighted as one of the major constraints by all interviewees. Contractors and developers have attempted to overcome this constraint by among others scheduling of activities in autumn and summer. For instance turbine installation and cable laying are done in autumn and summer. In recent times however, purpose built vessels and technologies such as the blade gripper have been developed to facilitate offshore installation works in harsh weather conditions.

7. Conclusions

This paper set out to study the challenges faced in the installation of offshore wind farms constructed under ”inner sea” conditions.To support this endeavour we mobilized a framework of understanding of operations management and –strategy concepts and selected two wind farms for qualitative study. The framework suggests a focus on capacity, process technology, product development, manufacturing and transportation. A number of challenges have been identified and discussed, broadly occurring in all parts of the framework. Challenges include failure of mobilized machines to perform work and presence of unknown items on the seabed such as unexploded objects left in the sea due to earlier human activities. Turbine sizes are increasing as the industry players seek to effectively tap the wind resources offshore. This however results in larger and heavier components which require larger vessels equipped to handle heavy loads and render road transport unfeasible. These changes necessitate cooperation between the players that participate in this fragmented sector. Some challenges are site specific, for instance seabed conditions, thus requiring each project to be carefully planned as a unique case. Solutions to site specific challenges may also come from experiences from similar projects. The installation activities are weather dependent and include frozen water in winter, high wind speed and sea tide. For these persisting challenges, it is recommended that their impact should be considered during the planning of activities, having appropriate risk sharing and allowing time contingency in scheduling. Logistical challenges can be reduced through the location of turbine manufacturing facilities close to sea, which is especially feasible at ”inner sea”locations.

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